

# Forces

Lecturer:

Professor Stephen T. Thornton

Reading Quiz: Which of Newton's laws refers to an action and a reaction acceleration?

A) First law.

B) Second law.

C) Third law.

D) This is a trick question. There is no such thing.

# Answer: D

Newton's third law is often known by its abbreviated form, "for every action there is an equal and opposite reaction". But it refers to force, not acceleration.

# Last Time

Two and three dimensional motion

Projectile motion

Relative motion

# Today

Forces

Newton's First Law

Newton's Second Law

Newton's Third Law

# Newton's Laws of Motion

We now learn about **FORCES**

Operational definition: Forces are pushes and pulls.

Look at spring scale.

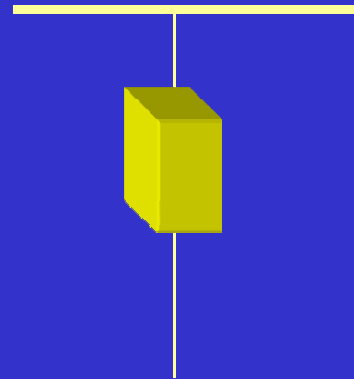
# Newton's First Law

*A body in motion tends to stay in motion unless acted upon by an external (outside) net force.*

Do demos: scooter  
air track  
hit the nail on the head  
tablecloth jerk  
bottle and pencil  
hanging masses (quizzes).

# Conceptual Quiz.

If we jerk on the bottom string, what happens?



- A) Top string breaks.
- B) Bottom string breaks.
- C) Can't possibly tell; it will happen randomly.



**Answer: B) bottom string breaks.**

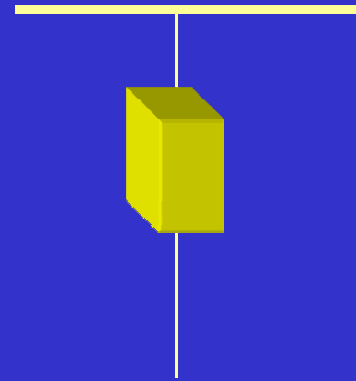
The bottom string breaks, because the mass is large and has lots of inertia.

The heavy mass will not respond to a quick jerk.

# Conceptual Quiz.

Now we pull slowly on the bottom string. What happens?

- A) Top string breaks.
- B) Bottom string breaks.
- C) Can't possibly tell; it will happen randomly.



Answer: A) top string breaks.

The top string breaks now, because we are pulling slowly on it. The bottom string feels the force from our hand, but the top string feels the force from our hand plus the weight of the mass.

## ***Conceptual Quiz***

**A book is lying at rest on a table. The book will remain there at rest because:**

- A) there is a net force but the book has too much inertia**
- B) there are no forces acting on it at all**
- C) it does move, but too slowly to be seen**
- D) there is no net force on the book**
- E) there is a net force, but the book is too heavy to move**

## Conceptual Quiz

A book is lying at rest on a table. The book will remain there at rest because:

- A) there is a net force but the book has too much inertia
- B) there are no forces acting on it at all
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- E) there is a net force, but the book is too heavy to move

*There are forces acting on the book*, but the only forces acting are in the y-direction. Gravity acts downward, but the table exerts an upward force that is equally strong, so the two forces cancel, leaving no net force.

## So what have we learned?

Newton's first law is also known as the *law of inertia*.

Inertia means the body wants to keep its present motion, whether at rest or not.

If a body is moving at constant velocity, it wants to remain moving at constant velocity.

If at rest, it wants to remain at rest.

It keeps its inertia unless a **net** force acts on it!

# What about relative motion?

Do relativity car motion demo again.

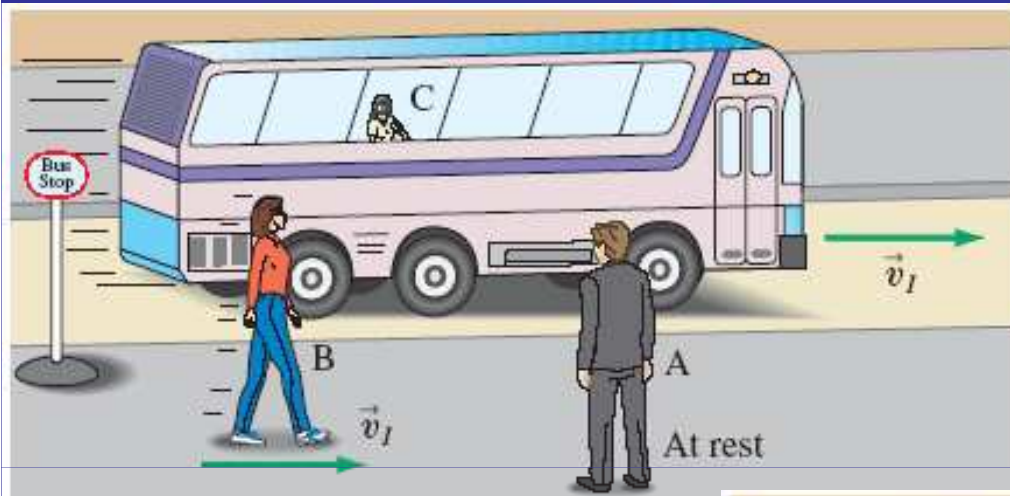
Imagine two observers:

Person A moving on cart.

Person B in classroom (you).

Watch ball shoot out of funnel. Do both observers indicate first law is obeyed when cart moves?

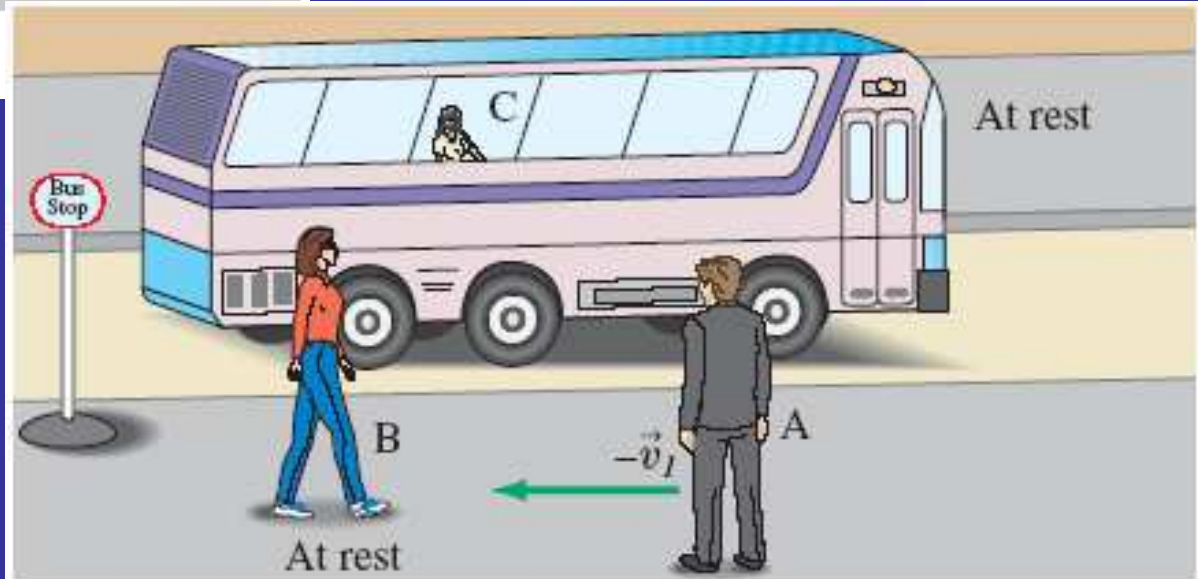
# Forces and Newton's First Law



(a) According to person A

Relative Motion – who is at rest?

No correct answer – each point of view is as good as the other



(b) According to Person B



# Inertial frames of reference

An inertial frame of reference is one in which the law of inertia (Newton's first law) is obeyed.

An accelerating frame is not an inertial frame of reference. There are lots of frames like this. Object moving in circular motion is good example.

# Mass

**Mass** is the measure of inertia of an object, sometimes understood as the quantity of matter in the object. In the SI system, mass is measured in **kilograms**.

Mass is **not weight**.

Mass is a **property** of an object. Weight is the force exerted on that object by gravity.

If you go to the Moon, whose acceleration of gravity is about  $1/6$  g, you will weigh much less. Your mass, however, will be the same.

# Newton's second law of motion

Let's do some experiments on the air track with a constant force (fan car). We will use the fan to push various masses and observe the acceleration of the masses.

Do experiments.

We learn that the acceleration is proportional to  $F/m$ .

$$a = \frac{F}{m}$$

Because there may be several forces on the object, we have to take the *net force*.

# Second Law

Determine the net force.

$$\vec{F}_{\text{net}} = \sum_i \vec{F}_i$$

Now Newton's Second Law appears as

$$\vec{F}_{\text{net}} = m\vec{a}$$

Unit is newton.  $1 \text{ N} = 1 \text{ kg}\cdot\text{m}/\text{s}^2$

# Forces

Lots of things to learn about forces.

Find net force – free-body diagrams are very helpful. Will do next time.

Different kinds of forces:

$W$  weight

$N$  normal force, also  $F_N$

$T$  tension, for example, a rope

$f$  friction

several others

# Forces are vectors

In some cases we will need to use the vector notation:

$$\vec{W}, \vec{N}, \vec{T}, \vec{f}$$

# Newton's Third Law

When an object 1 exerts a force on object 2, then object 2 will exert an equal, but opposite, force on object 1.

Forces always come in pairs and are equal and opposite.

The guys with the smashed faces are pushing back on the gloves just as hard!





# Math form of Newton's 3<sup>rd</sup> Law

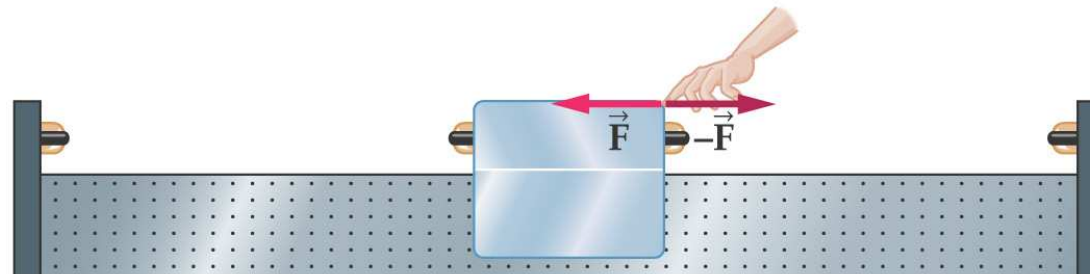
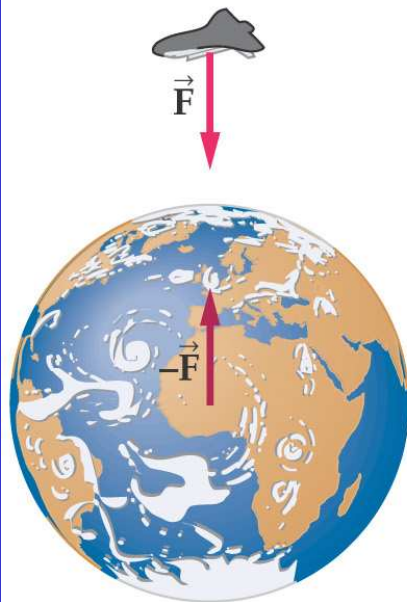
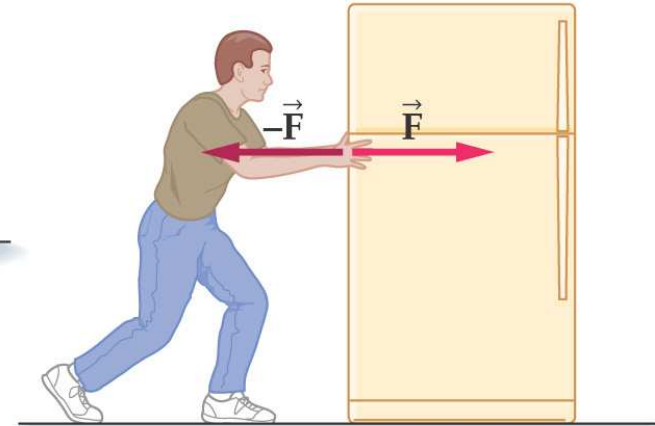
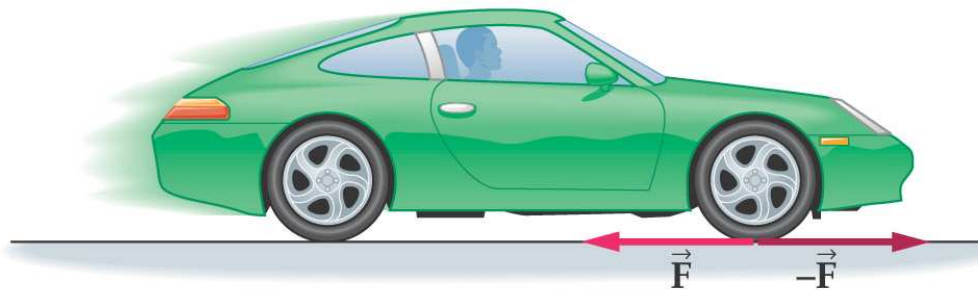
$$\boxed{\vec{F}_{12} = -\vec{F}_{21}}$$

Force on body 1 due to 2,  $\vec{F}_{12}$ , is equal and opposite to the force on 2 due to 1,  $\vec{F}_{21}$ .

We often say “for every action there is an equal and opposite reaction”.

*Law of action and reaction.*

# Examples of Action-Reaction Force Pairs

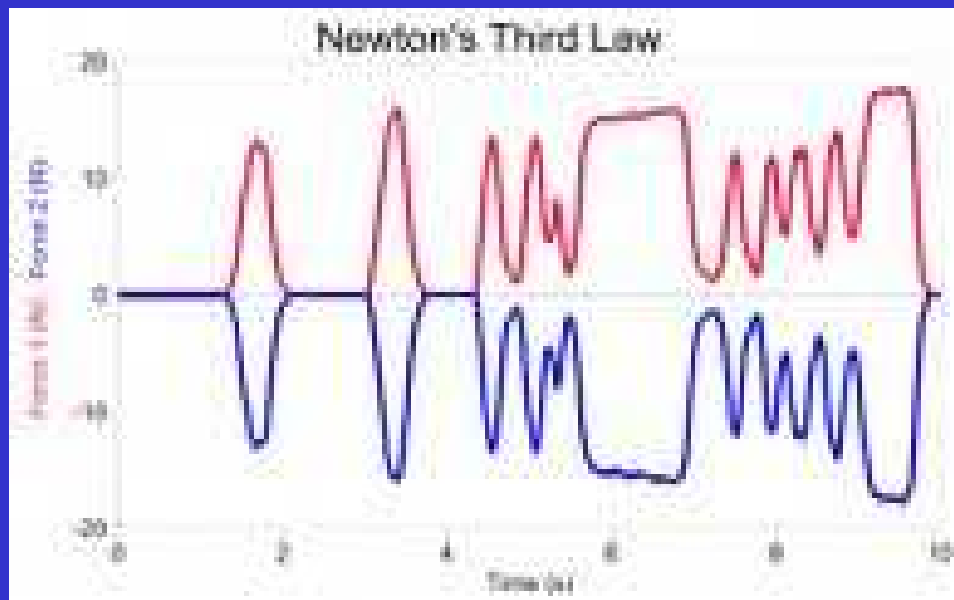
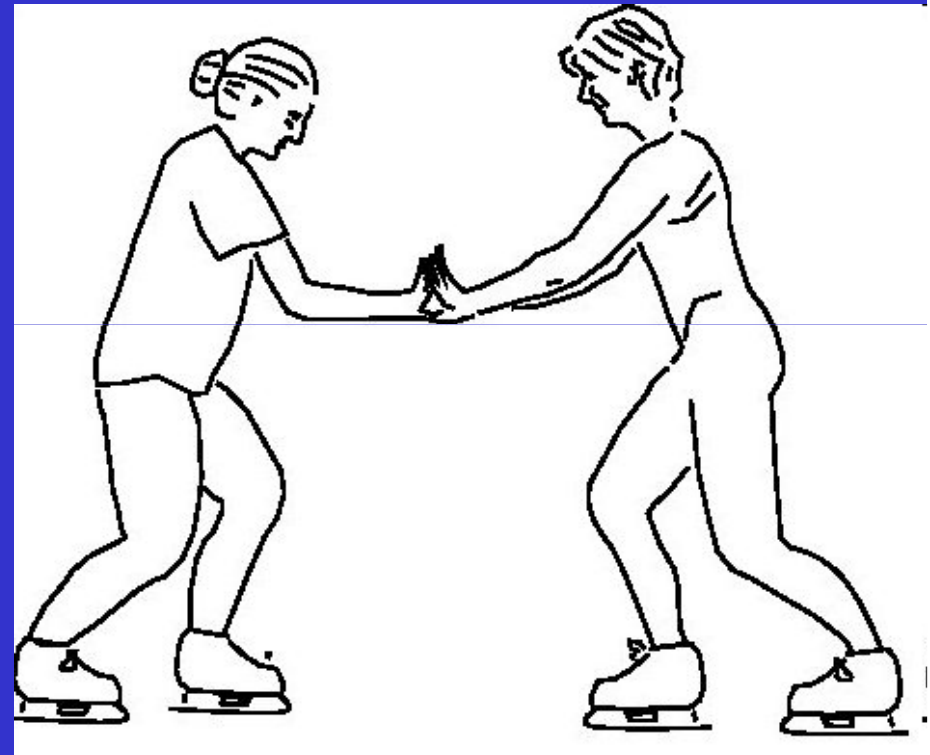


# Do demos

Air track reaction cars

Two carts with students  
(no time to do carts)

PASCO force probes



# Important Points

Action-reaction force pairs always act on different objects!

When dealing with forces, we want the  $\vec{F}_{\text{net}}$  on a particular object. In a 3<sup>rd</sup> law force pair, one force acts on one object and the other force acts on the other object.

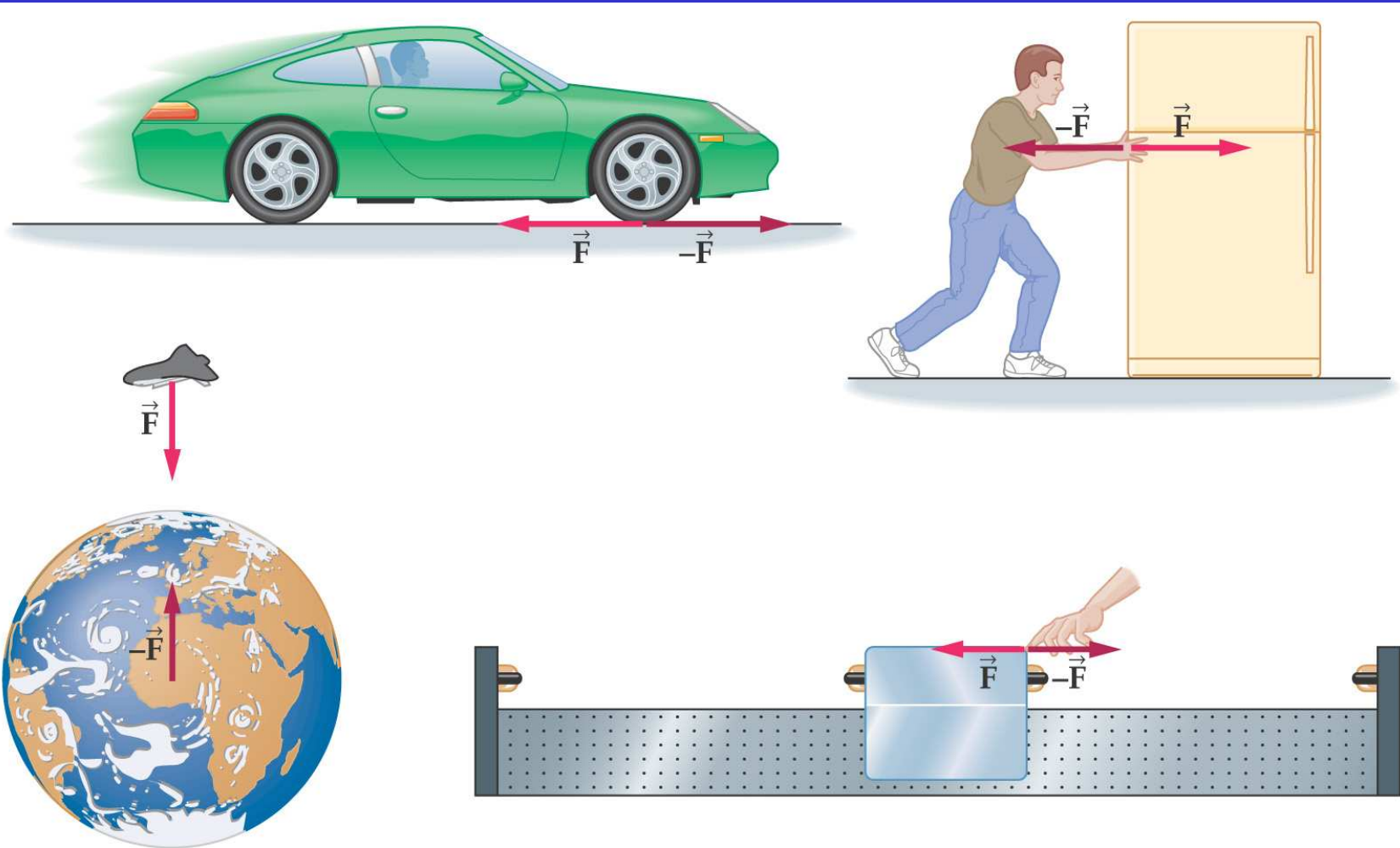
**This is a big source of confusion!**

# Newton's Third Law of Motion



A key to the correct application of the third law is that *the forces are exerted on different objects*. Make sure you don't use them as if they were acting on the *same object*.

# Example – which object is the force acting upon?



## Conceptual Quiz

A hockey puck slides on ice at **constant velocity**.

What is the **net** force acting on the puck?

- A) more than its weight
- B) equal to its weight
- C) less than its weight but more than zero
- D) depends on the speed of the puck
- E) zero

## Conceptual Quiz

A hockey puck slides on ice at **constant velocity**.

What is the **net** force acting on the puck?

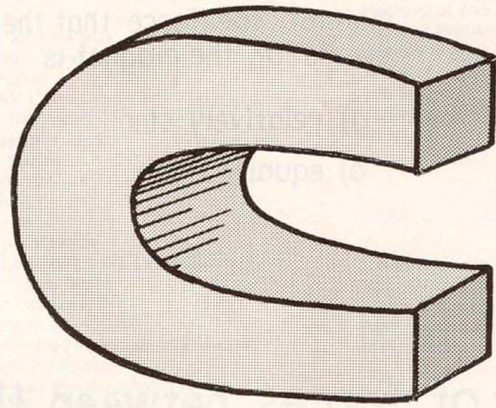
- A) more than its weight
- B) equal to its weight
- C) less than its weight but more than zero
- D) depends on the speed of the puck
- E) zero

The puck is moving at a **constant velocity**, and therefore it is **not accelerating**. Thus, there must be **no net force** acting on the puck.

**Follow-up:** Are there any forces acting on the puck? What are they?



## FIGURING PHYSICS

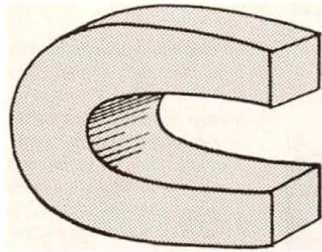


Compared to the huge force that attracts an iron tack to a strong magnet, the force that the tack exerts on the magnet is

- a) relatively small
- b) equally huge

Skipped as quiz

# FIGURING PHYSICS



Compared to the huge force that attracts an iron tack to a strong magnet, the force that the tack exerts on the magnet is

- a) relatively small
- b) equally huge

Answer: **B**

The pair of forces between the tack and magnet comprises a single interaction and both are equal in magnitude and opposite in direction—Newton's third law.

Like which pulls harder on the stretched rubber band—my thumb or my finger?

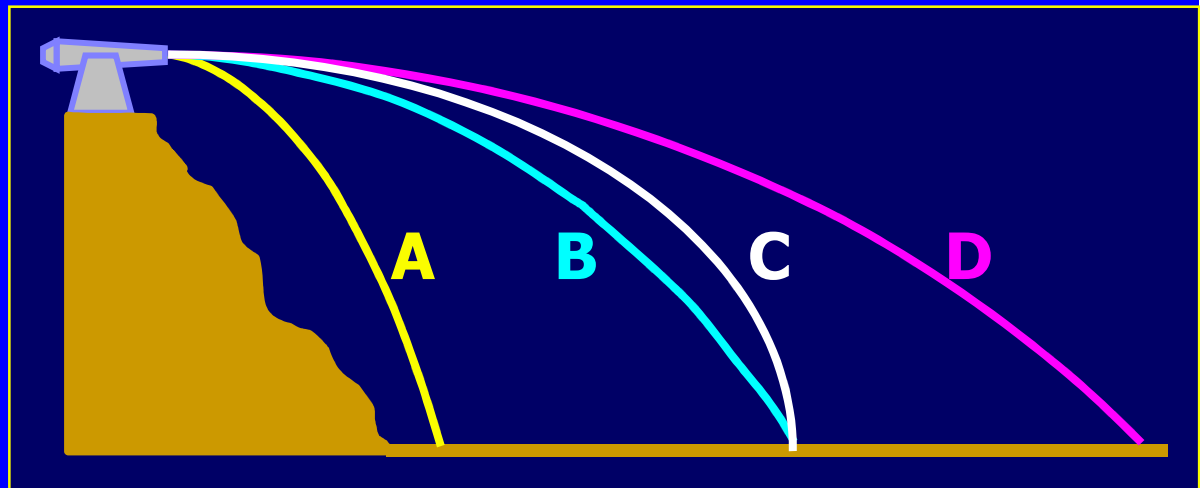


Forces are vectors. We separate forces into components and find motion for each component.

You need to work lots of problems to see how this works.

## Conceptual Quiz

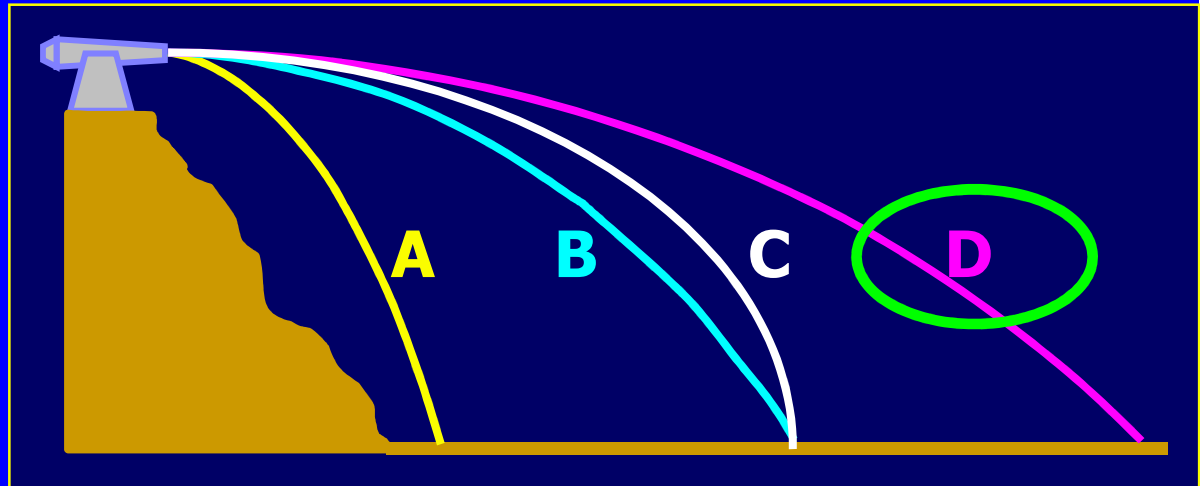
For a cannon on **Earth**, the cannonball would follow **path B**.  
Instead, if the same cannon were on the **Moon**, where  $g = 1.6 \text{ m/s}^2$ , which path would the cannonball take in the same situation?



## Conceptual Quiz

For a cannon on **Earth**, the cannonball would follow **path B**. Instead, if the same cannon were on the **Moon**, where  $g = 1.6 \text{ m/s}^2$ , which path would the cannonball take in the same situation?

The ball will spend more time in flight because  $g_{\text{Moon}} < g_{\text{Earth}}$ . With more time, it can travel farther in the horizontal direction.



## ***Conceptual Quiz***

The relativity cart is being pulled along a horizontal track by an external force (a weight hanging over the table edge) and accelerating. It fires a ball straight out of the cannon as it moves. After it is fired, what happens to the ball?

- A) it depends upon how much the track is tilted**
- B) it falls behind the cart**
- C) it falls in front of the cart**
- D) it falls right back into the cart**
- E) it remains at rest**

## ***Conceptual Quiz***

The relativity cart is being pulled along a horizontal track by an external force (a weight hanging over the table edge) and accelerating. It fires a ball straight out of the cannon as it moves. After it is fired, what happens to the ball?

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Now the acceleration of the cart is completely unrelated to the ball. In fact, the ball does not have any horizontal acceleration at all, so it will lag behind the accelerating cart once it is shot out of the cannon.